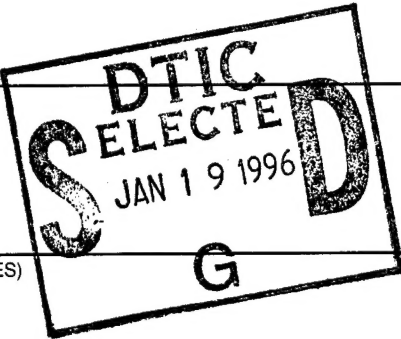


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Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.																								
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE See Title Page	3. REPORT TYPE AND DATES COVERED 1 February 1987 to 31 January 1991																						
4. TITLE AND SUBTITLE Use Title on Reprint One Copy of Each Submitted			5. FUNDING NUMBERS N00014-87-C-0146 OR0A444C- 43051 43051S4																					
6. AUTHOR(S) See Individual Articles																								
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Vanderbilt University Nashville TN 37332 (615-322-2786)																								
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 North Quincy Street Arlington, VA 22217-5660			8. PERFORMING ORGANIZATION REPORT NUMBER																					
10. SPONSORING/MONITORING AGENCY REPORT NUMBER																								
11. SUPPLEMENTARY NOTES Each Paper Summarized on first page. Journal articles submitted as contract reports. All work performed under Government contract.																								
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE																					
13. ABSTRACT (Maximum 200 words) See first page of Article	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td colspan="2" style="padding: 5px;">Accession For</td> </tr> <tr> <td style="padding: 5px;">NTIS CRA&I</td> <td style="padding: 5px; text-align: center;"><input checked="" type="checkbox"/></td> </tr> <tr> <td style="padding: 5px;">DTIC TAB</td> <td style="padding: 5px; text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td style="padding: 5px;">Unannounced</td> <td style="padding: 5px; text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td colspan="2" style="padding: 5px;">Justification</td> </tr> <tr> <td colspan="2" style="padding: 5px;">By _____</td> </tr> <tr> <td colspan="2" style="padding: 5px;">Distribution /</td> </tr> <tr> <td colspan="2" style="padding: 5px;">Availability Codes</td> </tr> <tr> <td style="padding: 5px; width: 30%;">Dist</td> <td style="padding: 5px;">Avail and/or Special</td> </tr> <tr> <td style="padding: 5px; text-align: center;">A-1</td> <td style="padding: 5px;"></td> </tr> </table> <div style="font-size: 2em; margin-top: 20px; text-align: center;">19960104 061</div>				Accession For		NTIS CRA&I	<input checked="" type="checkbox"/>	DTIC TAB	<input type="checkbox"/>	Unannounced	<input type="checkbox"/>	Justification		By _____		Distribution /		Availability Codes		Dist	Avail and/or Special	A-1	
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14. SUBJECT TERMS Free Electron Lasers Medicine Biology Biomedical Instrumentation Energy Cells			15. NUMBER OF PAGES 00																					
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED			16. PRICE CODE																					
18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED		19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED		20. LIMITATION OF ABSTRACT UL																				

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Physics of Free-Electron-Laser Applications in the Visible and Infrared

INTRODUCTION

It is now eighteen years since John Madey published a paper pointing out that a high-brightness relativistic electron beam traversing a spatially periodic magnetic field could stimulate the emission of photons over a broad range of wavelengths, indeed, from the far infrared to the ultraviolet. In a way, the free-electron laser was the ultimate homage paid by the laser, viewed as an optical device, to its antecedents in radar and electron-beam science and technology dating back into the 1940's.

In the intervening years, successful infrared and visible free-electron-laser (FEL) experiments, for example, at Stanford, Orsay, Santa Barbara, and Los Alamos, have shown significant promise for applications based on the unique optical characteristics of the FEL. A variety of accelerators can provide the high-brightness electron beams necessary for the FEL: room-temperature pulsed linear accelerators, superconducting accelerators, storage rings, and Van de Graaff generators have all been successfully used so far for this purpose. The existence of this variegated collection of pumps for the stimulated emission generated in the FEL implies a correspondingly broad range of temporal pulse shapes, interpulse spacings, pulse-repetition frequencies, output powers, and spectral ranges for users.

With the increasing maturity of the free-electron laser comes a new phase of scientific opportunity for those who are primarily laser users rather than laser physicists. During the past two years, FEL users' facilities at Stanford University and the University of California at Santa Barbara began to provide significant quantities of time to photon users, particularly in surface and materials science and biomedical studies. In the coming year, new FEL users' facilities devoted to biomedical and materials research as well as to FEL development will begin to operate at Vanderbilt and Duke; plans for additional facilities of this type are already far advanced.

Free-electron lasers now support significant experimental activities in a wide range of scientific and technological applications, including biomedical research. The spectrum of wavelengths now demonstrated in FEL's ranges from 0.25 to 800 μm , the region that includes atomic and molecular transitions as well as many elementary excitations in solids. While at least some parts of this spectral region can be covered by conventional lasers, the FEL has at least two major benefits compared with conventional lasers:

- The variety of FEL accelerator types offers the potential for decoupling the laser temporal-pulse structure and power output from the constraints of discharge or laser-pumping schemes and
- Beyond a wavelength of approximately 10 μm , the FEL has significantly greater tunability and higher power than any currently available lasers.

In addition, the fact that the interpulse spacing can be set much shorter than that available from mode-locked pulse trains (the Mark III FEL at Stanford and slated for installation at Vanderbilt, for example, has a rf accelerator frequency of 2.865 GHz, so that its pulses are 330 psec apart) makes it possible to carry out experiments in which the laser pulses follow one another on a time scale comparable with many relaxation times of physical, chemical, and biological interest.

In this special issue of *Journal of the Optical Society of America B*, we have collected a round dozen papers describing the physics of FEL applications in the visible and infrared. First, the companion papers on two-color FEL technology and applications suggest new opportunities in fundamental science that can be attained with the unique technology of the free-electron laser. In the near infrared, additional condensed-matter studies and surface science—particularly vibrational spectroscopy—have become possible with existing free-electron lasers. The gas-loaded free-electron laser can shift infrared FEL output into the visible, where work done with existing tabletop lasers can suggest ways in which the FEL, with its unique temporal pulse characteristics, might enhance our understanding of laser-induced processes both in materials science and in biomedical research. Finally, the far-infrared region was pinpointed early on as a place where exciting studies could be carried out in condensed-matter physics and biological physics. The papers submitted for this issue covering both recent research applications and new possibilities for direct excitation of far-infrared vibrational modes in solids suggest that this promise of the FEL is already being realized.

However, as with any new photon source, much of the challenge in developing new science will revolve around "thinking the unthinkable," or at least thinking the heretofore unthought. Thus the material ranges from reports of experimental results to inform speculations on possible future directions in FEL applications based on the unique properties of the FEL. Even though the *Journal of the Optical Society of America B* is an archival journal with a retrospective point of view, we hope that the speculation will stimulate as yet unthought, forward-looking applications of the FEL in the larger optical-science community.

Richard F. Haglund, Jr.
Howard Schlossberg

Feature Editors
*Physics of Free-Electron-Laser Applications
in the Visible and Infrared*

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